

Method and device for scanning a disc-shaped information storage medium

FIELD OF THE INVENTION

The present invention relates in general to a disc drive apparatus for writing information to a disc-shaped information storage medium and for reading from a disc-shaped information carrier. More particularly, the present invention relates to a disc drive apparatus
5 for handling an optical storage disc; hereinafter, such disc drive apparatus will also be indicated as "optical disc drive". It is to be noted, however, that the present invention is not restricted to optical discs, since the gist of the present invention is also applicable to other types of discs.

10 BACKGROUND OF THE INVENTION

As is commonly known, an optical storage disc comprises at least one track of storage space, either in the form of a continuous spiral or in the form of multiple concentric circles, where information may be stored in the form of a data pattern. Optical discs may be read-only type, where information is recorded during manufacturing, which information can
15 only be read by a user. The optical storage disc may also be a writable type, where information may be stored by a user. For writing information in the storage space of the optical storage disc, or for reading information from the disc, an optical disc drive comprises, on the one hand, rotating means for receiving and rotating an optical disc, and on the other hand optical scanning means for generating an optical beam, typically a laser beam, and for
20 scanning the storage track with said laser beam. Since the technology of optical discs in general, i.e. the way in which information can be stored in an optical disc, and the way in which optical data can be read from an optical disc, is commonly known, it is not necessary here to describe this technology in more detail.

For rotating the optical disc, an optical disc drive typically comprises a motor,
25 which drives a hub engaging a central portion of the optical disc. Usually, the motor is implemented as a spindle motor, and the motor-driven hub may be arranged directly on the spindle axle of the motor.

For optically scanning the rotating disc, an optical disc drive comprises a light beam generator device (typically a laser diode), an objective lens for focussing the light beam

in a focal spot on the disc, and an optical detector for receiving the reflected light reflected from the disc and for generating an electrical detector output signal. The optical detector usually comprises multiple detector segments, each segment providing an individual segment output signal.

5 During operation, the light beam should remain focussed on the disc. To this end, the objective lens is arranged axially displaceable, and the optical disc drive comprises focal actuator means for controlling the axial position of the objective lens. Further, the focal spot should remain aligned with a track or should be capable of being displaced from a current track to a new track. To this end, at least the objective lens is mounted radially
10 displaceable, and the optical disc drive comprises radial actuator means for controlling the radial position of the objective lens.

 A control circuit drives the motor, and drives the actuator means, so as to position the focus spot of the laser beam with respect to the correct track, and to rotate the disc at a desired velocity. In setting the disc velocity, the control circuit may apply different
15 control strategies. In one control strategy, the disc motor is driven to rotate at a constant rotational frequency, causing the disc to rotate at a constant angular velocity; this mode of operation is indicated as CAV mode.

 In another control strategy, the rotational frequency of the disc motor is selected in relation to the radial position of the laser beam focus spot, such that the disc
20 rotates at a constant linear velocity; this mode of operation is indicated as CLV mode. Assuming that the linear bit density of the track is constant, CLV mode leads to a constant bit rate, whereas CAV mode leads to a bit rate which is higher for the outer track than for the inner track.

 A disc drive apparatus may be capable of operating in one mode only, at one
25 fixed setting. For instance, a disc drive may only be capable of operating in a CAV mode at one fixed angular velocity independent of the radius. Or, a disc drive may only be capable of operating in a CLV mode at one fixed linear velocity. However, the present invention relates to a disc drive apparatus having a variable velocity setting and/or being capable to switch operating mode, i.e. to selectively operate in CAV mode or CLV mode; this freedom of
30 selecting velocity and/or mode will generally be referred to as setting mode/velocity.

 Disc drive devices capable of setting mode/velocity are known per se. For instance, reference is made to EP-1.052.638, which describes a disc drive which divides a disc into a plurality of zones. For each of the zones, an operational mode is fixed, and an associated velocity is fixed. So, one zone may be operated in CAV mode at a first rotational

speed, a second zone may be operated in CAV mode at a second rotational speed, and a third zone may be operated in CLV mode at a certain linear velocity, etc. However, the distinction between zones, and the modes and velocities associated with the zones, are defined in advance, the definitions being fixed. A disadvantage of such a pre-defined definition of
5 operating mode and velocity is that the apparatus is usually not operating as efficiently as possible in terms of power consumption.

The present invention aims to overcome this disadvantage.

More particularly, an objective of the present invention is to provide an improved disc drive apparatus, capable of operating at reduced power consumption without
10 compromising performance.

SUMMARY OF THE INVENTION

According to an important aspect of the present invention, a disc drive is capable of dynamically selecting operating mode and/or velocity and/or execution order on
15 the basis of actions to be taken, with a view to minimizing the power consumption of those actions.

According to a further important aspect of the present invention, a disc drive is capable of receiving a plurality of action commands, to store the commands in a command buffer, to calculate a most efficient execution order for these commands, and to perform the
20 commands in the calculated most efficient execution order.

According to a preferred embodiment of the present invention, a disc drive is capable of receiving a plurality of action commands, to store the commands in a command buffer, to calculate a most efficient execution order for these commands in combination with a most efficient mode and/or velocity selection, and to perform the commands in the
25 calculated most efficient execution order at the correspondingly selected most efficient mode and/or velocity.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects, features and advantages of the present invention will
30 be further explained by the following description with reference to the drawings, in which same reference numerals indicate same or similar parts, and in which:

Figure 1 schematically illustrates relevant components of an optical disc drive apparatus;

Figures 2A and 2B are graphs illustrating CAV mode and CLV mode, respectively;

Figures 3A and 3B are graphs illustrating CAV mode and CLV mode, respectively, for a case where the velocity depends on a radius range of the disc;

5 Figure 4 is a graph illustrating selectable CAV mode and CLV mode;

Figures 5A and 5B are graphs illustrating the amount of energy required for reading/writing a certain amount of data in CAV mode or in CLV mode;

Figure 6 is a flow diagram illustrating a first embodiment of a read/write process according to the present invention;

10 Figure 7 is a flow diagram illustrating a second embodiment of a read/write process according to the present invention;

Figure 8 is a flow diagram illustrating a third embodiment of a read/write process according to the present invention;

15 Figure 9 is a flow diagram illustrating a fourth embodiment of a read/write process according to the present invention;

Figure 10 is a flow diagram illustrating a fifth embodiment of a read/write process according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

20 Figure 1 schematically illustrates an optical disc drive apparatus 1, suitable for storing information on or reading information from an optical disc 2, typically a DVD or a CD. For rotating the disc 2, the disc drive apparatus 1 comprises a motor 4 fixed to a frame (not shown for sake of simplicity), defining a rotation axis 5.

The disc drive apparatus 1 further comprises an optical system 30 for scanning
25 tracks (not shown) of the disc 2 by an optical beam. More specifically, in the exemplary arrangement illustrated in Figure 1, the optical system 30 comprises a light beam generating means 31, typically a laser such as a laser diode, arranged to generate a light beam 32. In the following, different sections of the light beam 32, following an optical path 39, will be indicated by a character a, b, c, etc added to the reference numeral 32.

30 The light beam 32 passes a beam splitter 33, a collimator lens 37 and an objective lens 34 to reach (beam 32b) the disc 2. The light beam 32b reflects from the disc 2 (reflected light beam 32c) and passes the objective lens 34, the collimator lens 37 and the beam splitter 33 (beam 32d) to reach an optical detector 35. The objective lens 34 is designed

to focus the light beam 32b in a focus spot F on a recording layer (not shown for sake of simplicity) of the disc.

The disc drive apparatus 1 further comprises an actuator system 50, which comprises a radial actuator 51 for radially displacing the objective lens 34 with respect to the disc 2. Since radial actuators are known per se, while the present invention does not relate to the design and functioning of such a radial actuator, it is not necessary here to discuss the design and functioning of a radial actuator in great detail.

For achieving and maintaining a correct focusing, exactly on the desired location of the disc 2, said objective lens 34 is mounted so as to be axially displaceable, while further the actuator system 50 also comprises a focus actuator 52 arranged for axially displacing the objective lens 34 with respect to the disc 2. Since focus actuators are known per se, while the design and operation of such a focus actuator is not a subject of the present invention, it is not necessary here to discuss the design and operation of such a focus actuator in great detail.

For achieving and maintaining a correct tilt position of the objective lens 34, the objective lens 34 may be mounted pivotably; in such a case, as shown, the actuator system 50 also comprises a tilt actuator 53 arranged for pivoting the objective lens 34 with respect to the disc 2. Since tilt actuators are known per se, while the design and operation of such a tilt actuator is not a subject of the present invention, it is not necessary here to discuss the design and operation of such a tilt actuator in great detail.

It is further noted that means for supporting the objective lens with respect to an apparatus frame, and means for axially and radially displacing the objective lens, as well as means for pivoting the objective lens, are generally known per se. Since the design and operation of such supporting and displacing means is not a subject of the present invention, it is not necessary here to discuss their design and operation in great detail.

It is further noted that the radial actuator 51, the focus actuator 52 and the tilt actuator 53 may be implemented as one integrated actuator.

The disc drive apparatus 1 further comprises a control circuit 90 having a first output 91 coupled to a control input of the radial actuator 51, having a second output 92 coupled to a control input of the focus actuator 52, having a third output 93 coupled to a control input of the tilt actuator 53, and having a fourth output 94 connected to a control input of the motor 4. The control circuit 90 is designed to generate at its first control output 91 a control signal S_{CR} for controlling the radial actuator 51, to generate at its second output 92 a control signal S_{CF} for controlling the focus actuator 52, to generate at its third output 93 a

control signal S_{CT} for controlling the tilt actuator 53, and to generate at its fourth output 94 a control signal S_{CM} for controlling the motor 4.

The control circuit 90 further has a read signal input 95 for receiving a read signal S_R from the optical detector 35.

5 For scanning the optical disc 2 (in a reading or writing operation), the control circuit 90 drives the motor 4 (control signal S_{CM}) to rotate at a certain rotational frequency. If the disc 2 is mounted directly on an output shaft of the motor (as depicted in the Figure), the rotational frequency of the disc 2 is identical to the rotational frequency of the motor, but it is alternatively possible that the disc drive apparatus 1 comprises a transmission system
10 between motor and disc, in which case the rotational frequency of the disc 2 may differ from the rotational frequency of the motor, as will be clear to a person skilled in the art. In the following, the rotational frequency of the disc 2 will be indicated as ω [s^{-1}]; the rotational velocity of the disc will be $2\pi\omega$ [rad/s].

The control circuit 90 may operate in a CAV mode, in which case the
15 rotational frequency ω is independent of the radial position of the scanning focus spot F. The control circuit 90 may also operate in a CLV mode, in which case the linear velocity V of the scanning focus spot F with respect to the track is independent of the radial position of the scanning focus spot F.

ω and V follow the relationship $V = 2\pi\omega \cdot R$, R being the radius of the radial
20 position of the scanning focus spot F. In the case of operating in CAV mode, the linear scanning velocity is proportional to the radius of the radial position of the scanning focus spot F. In the case of operating in CLV mode, the rotational frequency ω of the disc is inversely proportional to the radius of the radial position of the scanning focus spot F. This is illustrated in Figures 2A and 2B, which are schematical graphs indicating ω and V (vertical
25 axis, arbitrary units) as a function of R (horizontal axis, arbitrary units) for the case of CAV (Figure 2A) and CLV (Figure 2B).

In Figures 2A and 2B, ω and V, respectively, are constant over the entire range of R from the innermost radius R_{inner} to the outermost radius R_{outer} . The control circuit 90 of the disc drive 1 according to the present invention is preferably capable of varying the value
30 of ω or V, respectively, depending on circumstances, as will be explained later. An example of this is illustrated in Figures 3A and 3B, which are graphs comparable to Figures 2A and 2B, respectively.

Figure 3A illustrates a case where the control circuit 90 is operating in CAV mode at a first constant rotational frequency ω_1 in a first range from the innermost radius

R_{inner} to a certain first radius R_1 ; the control circuit 90 is operating in CAV mode at a second constant rotational frequency ω_2 in a second range from said first radius R_1 to a certain second radius R_2 ; and the control circuit 90 is operating in CAV mode at a third constant rotational frequency ω_3 in a third range from said second radius R_2 to the outermost radius R_{outer} .

Figure 3B illustrates a case where the control circuit 90 is operating in CLV mode at a first constant linear velocity V_1 in a first range from the innermost radius R_{inner} to a certain first radius R_1 ; the control circuit 90 is operating in CLV mode at a second constant linear velocity V_2 in a second range from said first radius R_1 to a certain second radius R_2 ; and the control circuit 90 is operating in CLV mode at a third constant linear velocity V_3 in a third range from said second radius R_2 to the outermost radius R_{outer} .

In Figures 2A/3A and 2B/3B, the control circuit 90 is always operating in CAV mode or CLV mode, respectively, albeit at different values for the constant rotational frequency and the constant linear velocity, respectively. The control circuit 90 of the disc drive 1 according to the present invention is preferably capable of selectively operating in CAV mode or in CLV mode, depending on circumstances, as will be explained later. An example is illustrated in Figure 4, which is comparable to Figures 2A and 2B. Figure 4 illustrates a case where the control circuit 90 is operating in CAV mode at a certain constant rotational frequency ω_1 in a first range from the innermost radius R_{inner} to a certain first radius R_1 . The control circuit 90 is operating in CLV mode at a certain constant linear velocity V_1 in a second range from said first radius R_1 to the outermost radius R_{outer} .

According to an important aspect of the present invention, the control circuit 90 is designed to select its mode of operation (either CAV mode or CLV mode), and/or the value of constant rotational frequency, and/or the value of constant linear velocity, on the basis of power consumption considerations, as will be described later.

For a disc drive apparatus executing a task, the amount of energy consumed can be different, depending on whether the drive is operating in CAV mode or in CLV mode. In this respect, the phrase "executing a task" is used to cover a variety of individual activities, such as performing a jump from a start track to a target track, reading/writing a certain amount of data from/at a certain track location, etc. For the activity "reading" or "writing", the power consumption will be substantially equal in CAV and in CLV mode, but the time required for reading/writing a certain amount of data can be different (in this respect, it is noted that the consumed energy is equal to the consumed power multiplied by the required time, or, more accurately, $ENERGY = \int \{POWER(t)d(t)\}$). The difference will depend on the

radius of the data storage location, but also on the state the disc drive is in when starting the activity. For instance, scanning at the inner radius of the disc is substantially faster in CLV mode as compared to CAV mode, assuming that the rotational frequency at the outer radius is the same for the CLV mode and the CAV mode. Thus, the energy consumption associated with reading/writing a certain amount of data from/at the inner radius is substantially less in CLV mode as compared to CAV mode. However, when the disc drive is idle or the current location of the focus spot F is at the outer radius, the required scanning operation would require a spinning-up of the disc to the corresponding rotational frequency at the inner radius (see Figure 2B), which is an activity that consumes much energy, whereas maintaining a constant rotational frequency mainly requires only energy sufficient to compensate friction.

Thus, depending on circumstances, it may be more advantageous to use CAV mode or to use CLV mode. Although the target radius plays a role, as does the start radius, these parameters, taken alone, are not decisive: for instance, if the disc drive is currently addressing the outer disc radius while operating in CAV mode, the jump to the inner radius does not necessarily involve any spinning-up, and it may be advantageous to switch from CAV mode to CLV mode. As another example, if the amount of data to be handled is only very small, the lower power consumption associated with the scanning action does not compensate the energy consumed by spinning-up the disc, and it may be advantageous to continue in CAV mode, whereas, if the amount of data to be handled is large, the balance can tip in favour of using CLV mode.

In the following, a more elaborate discussion will be given of many aspects influencing the power consumption of an optical disc drive, especially in conjunction with the choice between CAV and CLV mode.

A disc drive apparatus comprises many components that consume power, such as the disc motor, the actuator systems, the laser device, the laser driver, bit detection and analog preprocessing circuitry, digital electronics, buffer memory, DC/DC converter.

When a disc drive apparatus is given a command (for writing and/or reading), the following phases are passed:

Initial spin-up: Assuming the disc drive is idle and the disc is not rotating, the disc has to be spun-up to a certain rotational frequency. The motor and motor driver are active; the laser, digital electronics, analog preprocessing circuitry and actuator systems are OFF.

When operating in CAV mode, the disc is always spun-up to the same rotational frequency, independent of radius; when operating in CLV mode, the disc is spun-

up to a rotational frequency depending on the radius: at the inner radius, the disc is spun-up to a higher rotational frequency as compared to the outer radius. At the inner radius, the difference in rotational frequency can amount to a factor of 2, whereas at the outer radius, the rotational frequency will usually be the same for CAV and CLV. Depending on the radius,
5 the energy consumption can be substantially higher in CLV mode as compared to CAV mode.

Initialize optics: After initial spin-up, the optical system is initialized. The motor is rotating, normally at a constant frequency. The actuator systems for focus and tracking are turned on, as is the laser. The power consumption is mainly determined by the
10 laser and the laser driver.

Spin-up/down: When operating in CAV mode, no change of rotational frequency is required, but when operating in CLV mode, and when a jump to another location on the disc is necessary, the rotational frequency of the disc is to be changed. The change of rotational frequency can be performed simultaneously with a search action.

Search: The sledge is moving to the correct position with respect to the disc.
15 The laser, the actuator systems for focus and tracking, the analog preprocessing circuitry, and the digital electronics are ON. The search phase may partially overlap with the spin-up/down phase and/or the initial spin-up phase. The power consumption is mainly determined by the laser, the laser driver, and the signal processing electronics. The search is performed in the
20 same way, whether for CAV mode or CLV mode, so there will be little or no difference in energy consumption.

Read/Write: The actual reading/writing action is performed. The laser is ON. The analog preprocessing circuitry and the digital electronics are ON for performing detection, equalization, error correction. Also, the buffer is ON. The power consumption is
25 mainly determined by the laser, the laser driver, and the signal processing electronics.

In CLV mode, the read/write time is independent of location on disc. However, the stationary power consumption of the motor increases from the outer radius to the inner radius, because the rotational frequency increases from the outer radius to the inner radius.

30 In CAV mode, the stationary power consumption of the motor is independent of location on disc. However, the read/write time increases from the outer radius to the inner radius.

Figures 5A and 5B are graphs illustrating the amount of energy required (E_{RW} ; vertical axis) for reading/writing a certain amount of data (number of data blocks; horizontal

axis). Figure 5A relates to a situation where reading/writing takes place at the inner radius of the disc, while figure 5B relates to a situation where reading/writing takes place close to the outer radius of the disc. Each Figure showag two curves, one for operation in CAV mode and one for operation in CLV mode.

5 In general, when comparing CLV mode with CAV mode, E_{RW} is smaller for CLV mode than for CAV mode, because the read/write time is shorter in CLV mode while the stationary power consumption of the motor is only a little bit higher in CLV mode. Close to the outer radius of the disc, the difference between the CAV characteristic and the CLV characteristic is practically zero, at least if the disc velocity is the same in both cases, which
10 usually is the case.

When multiple read/write actions are to be performed sequentially, the CLV mode is more energy-efficient than the CAV mode, as can be seen from Figures 5A-5B. However, when multiple read/write actions are to be performed with random disc accesses, the CLV mode involves changing the rotational frequency (speed-up/speed-down), which
15 requires extra energy. As long as this extra energy is less than the energy difference $E_{RW,diff}$ (Figure 5A), the CLV mode is still advantageous, otherwise the CAV mode becomes advantageous.

The total energy $E_{COMMAND}$ required for executing a command can be expressed as:

$$20 \quad E_{COMMAND} = E_{UD} + E_{SEARCH} + E_{RW}$$

wherein

E_{UD} is the amount of energy required for spinning up or down,

E_{SEARCH} is the amount of energy required for searching,

E_{RW} is the amount of energy required for reading/writing.

25 The CLV mode is advantageous over the CAV mode, if the corresponding total energy $E_{COMMAND,CLV}$ is less than the total energy $E_{COMMAND,CAV}$, i.e. $E_{COMMAND,CLV} < E_{COMMAND,CAV}$

This condition is satisfied if:

$$E_{UD,CLV} + E_{SEARCH,CLV} + E_{RW,CLV} < E_{UD,CAV} + E_{SEARCH,CAV} + E_{RW,CAV}, \text{ or}$$

$$E_{UD,CLV} + E_{RW,CLV} < E_{UD,CAV} + E_{RW,CAV} \text{ (assuming } E_{SEARCH,CLV} = E_{SEARCH,CAV}), \text{ or}$$

$$30 \quad E_{UD,CLV} - E_{UD,CAV} < E_{RW,CAV} - E_{RW,CLV} = E_{RW,diff}$$

Whether or not this condition is satisfied depends, among other things, on the condition the disc drive is in: if the disc is already spinning, $E_{UD,CAV} = 0$, whereas $E_{UD,CLV} = 0$ only if the disc is already spinning at the correct frequency.

A disc drive may receive multiple commands. In a disc drive in accordance with the principles of the present invention, these commands are not necessarily executed immediately on receipt, and they are not necessarily executed in the order of receipt. The disc drive is adapted to store the commands in a waiting queue, and to execute the commands in command batches once the queue contains a sufficient number of commands, or after a predetermined waiting time has passed. The disc drive in accordance with the principles of the present invention is further adapted to determine the execution order of the commands in the queue such that the overall amount of energy required for the entire command batch is as low as possible.

A disc drive in accordance with the principles of the present invention can determine such a most efficient execution order with one and the same scanning mode (CAV, CLV) for all commands, and it is even possible that the disc drive is not capable of changing scanning mode. Preferably, however, a disc drive capable of changing scanning mode is adapted to select the scanning mode for each command, such that the overall amount of energy required for executing all commands with the selected scanning mode in the determined execution order is as low as possible.

Consider a case where the command queue contains three commands C1, C2, C3, received in this order. The disc drive can execute these commands in the order C1-C2-C3 as received, or in the opposite order C3-C2-C1, or for instance in the order C1-C3-C2, or in any other order. The total number of possible orders in this case is equal to 6; in general, when the queue contains n commands, the total number of possible orders in this case is equal to $n!$

Each command can be executed in CAV mode or in CLV mode; more particularly, the first command can be executed in CAV mode or in CLV mode, the second command can be executed in CAV mode or in CLV mode, the third command can be executed in CAV mode or in CLV mode. In the case of three commands, there are 8 possible combinations (2^3) for mode selection. In general, when the number of mode possibilities is equal to m , the number of possibilities is equal to m^n .

Thus, in a case where the command queue contains three commands C1, C2, C3, which each can be executed in CAV mode or in CLV mode, the total number of possible combinations is equal to 48. In accordance with the present invention, the disc drive is adapted to select, from these 48 combinations, the combination which is associated with the minimum amount of energy consumption.

EXAMPLE 1

A first embodiment of a read/write process 100 in accordance with the present invention will be explained with reference to Figure 6. In a first step 101, a read/write command is received. The control circuit 90 estimates the amount of energy E_L expected to be consumed when this command is executed in CLV mode [step 102], and estimates the amount of energy E_A expected to be consumed when this command is executed in CAV mode [step 103]. As should be clear to a person skilled in the art, the steps 102 and 103 may be executed in opposite order, or simultaneously.

Then, the control circuit 90 decides whether E_L is larger or smaller than E_A [step 110]. If the control circuit 90 finds that E_L is smaller than E_A , the command is executed in CLV mode [step 121], otherwise the command is executed in CAV mode [step 122]. After executing the command, the process continues at first step 101.

In calculating the amount of energy expected to be consumed when executing the command, the control circuit 90 takes into account the conditions and parameters indicated earlier, such as current radius, target radius, current rotational frequency, amount of blocks to read/write, etc; this applies to the following examples also.

In the example, only two possible scanning modes (CAV; CLV) are taken into account. It should be clear to a person skilled in the art that similar considerations can be made when the control circuit 90 has more possible scanning modes to choose from. The same applies to the following examples also.

EXAMPLE 2

A second embodiment of a read/write process 200 in accordance with the present invention will be explained with reference to Figure 7. In a first step 201, a read/write command is received, the command containing a command completion time limit T_{LIMIT} . This is a restriction relating to the moment in time when the command must be completed, i.e. the speed at which the read/write process is executed. Such restriction applies in cases of time-critical data, such as for instance audio data, video data, etc.

The control circuit 90 estimates the amount of time t_L expected to be needed when this command is executed in CLV mode [step 202], and estimates the amount of time t_A expected to be needed when this command is executed in CAV mode [step 203]. As should be clear to a person skilled in the art, the steps 202 and 203 may be executed in opposite order, or simultaneously.

Then, the control circuit 90 compares t_L and t_A with the command completion time limit T_{LIMIT} [step 204]. If both t_L and t_A are smaller than the command completion time limit T_{LIMIT} , processing continues similarly as described with reference to Figure 6 [steps 211-222], and the command is executed in the scanning mode expected to consume the
5 lowest amount of energy.

If any one of t_L and t_A is larger than the command completion time limit T_{LIMIT} , or if both t_L and t_A are larger than the command completion time limit T_{LIMIT} , the completion time consideration is considered more important than the energy consumption consideration, and the command is executed in the scanning mode corresponding to the
10 shortest amount of estimated completion time [steps 230-232].

After executing the command, the process continues at first step 201.

In the above-described embodiments, the control circuit calculates the estimated amount of energy on a command-by-command basis. The decision whether a command is executed in a CAV mode or in a CLV mode is made for each command
15 individually. The commands are executed in the order in which they are received. In the following examples, multiple commands are collected in a queue buffer memory, and the commands may be executed in an order differing from the original order. The scanning mode may be selected individually for each command.

20 EXAMPLE 3

A third embodiment of a read/write process 300 in accordance with the present invention will be explained with reference to Figure 8. In a first step 301, a read/write command is received, and stored in the queue buffer memory [step 302]. These steps are repeated for subsequent commands, until a certain waiting time T_{WAIT} has passed [step 303];
25 the number of commands now in the queue buffer memory is indicated as n . In an alternative embodiment (not illustrated), said steps are repeated for subsequent commands until the queue buffer memory contains a predefined number n of commands.

For all $n!$ possible execution orders, the control circuit 90 estimates the amount of energy $E_L(i)$ expected to be consumed when these commands are executed in such order(i) in CLV mode [step 311], and determines the execution order consuming the lowest
30 amount of energy $E_{L,MIN}$ [step 312]. Likewise, for all possible execution orders, the control circuit 90 estimates the amount of energy $E_A(i)$ expected to be consumed when these commands are executed in such order(i) in CAV mode [step 313], and determines the execution order consuming the lowest amount of energy $E_{A,MIN}$ [step 314]. Then, the control

circuit 90 decides whether $E_{L,MIN}$ is larger or smaller than $E_{A,MIN}$ [step 320]. If the control circuit 90 finds that $E_{L,MIN}$ is smaller than $E_{A,MIN}$, all commands are executed in CLV mode in the execution order corresponding to the lowest amount of energy $E_{L,MIN}$ [step 321], otherwise all commands are executed in CAV mode in the execution order corresponding to the lowest amount of energy $E_{A,MIN}$ [step 322]. After executing the commands, the process continues at first step 301.

Thus, in this example, all commands are executed in the same scanning mode CAV or CLV, but the execution order is selected so that the amount of energy consumed is expected to be as low as possible.

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EXAMPLE 4

A fourth embodiment of a read/write process 400 in accordance with the present invention will be explained with reference to Figure 9. In a first step 401, a read/write command is received, and stored in the queue buffer memory [step 402]. These steps are repeated for subsequent commands, until a certain waiting time T_{WAIT} has passed [step 403]; the number of commands now in the queue buffer memory is indicated as n . In an alternative embodiment (not illustrated), said steps are repeated for subsequent commands until the queue buffer memory contains a predefined number n of commands.

In this example, the commands are executed in the order they have been received, but for each command the scanning mode is selected individually, so that the amount of energy expected to be consumed by the combination of all n commands is expected to be as low as possible. It is noted that this is not necessarily equivalent to each command being individually executed as energy-efficiently as possible. For instance, it may very well be that two commands, when considered alone, are each executed most efficiently in CLV mode, but, when considered in combination, the combination may be executed more efficiently in CAV mode.

Thus, the first command may be executed in CAV mode or in CLV mode, giving two possibilities. Independent of the mode setting for the first command, the second command may be executed in CAV mode or in CLV mode, giving a total of four possibilities. Independent of the mode setting for the first and second commands, the third command may be executed in CAV mode or in CLV mode, giving a total of eight possibilities. A skilled person will understand that there are 2^n possibilities for scanning mode setting of n commands.

For all these 2^n scanning mode setting possibilities, the control circuit 90 estimates the amount of energy $E_{ex}(i)$ expected to be consumed when the commands are executed with the corresponding mode setting [step 411], and selects the mode setting requiring the lowest amount of energy $E_{ex,MIN}$ [step 412]. Then, the control circuit 90
5 executes the commands from the queue buffer memory in the order of receipt, setting for each command the scanning mode as determined in step 412 [step 421]. After executing the commands, the process continues at first step 401.

EXAMPLE 5

10 A fifth embodiment of a read/write process 500 in accordance with the present invention will be explained with reference to Figure 10. In a first step 501, a read/write command is received, and stored in the queue buffer memory [step 502]. These steps are repeated for subsequent commands, until a certain waiting time T_{WAIT} has passed [step 503]; the number of commands now in the queue buffer memory is indicated as n . In an alternative
15 embodiment (not illustrated), said steps are repeated for subsequent commands until the queue buffer memory contains a predefined number n of commands.

The fifth embodiment is a combination of the third and the fourth embodiment, in that the control circuit 90 considers all $n!$ possible execution orders, and, for each possible execution order, considers all 2^n possibilities for scanning mode setting. Thus,
20 for all $2^n \cdot n!$ possible combinations of execution order and scanning mode setting, the control circuit 90 estimates the amount of energy $E_{ex}(i)$ expected to be consumed [step 511], and selects the combination of execution order and scanning mode setting requiring the lowest amount of energy $E_{ex,MIN}$ [step 512]. Then, the control circuit 90 executes the commands from the queue buffer memory in the order as determined in step 512, while setting for each
25 command the scanning mode as determined in step 512 [step 521]. After executing the commands, the process continues at first step 501.

EXAMPLE 6

A sixth embodiment of a read/write process in accordance with the present
30 invention is a combination of the fifth and the second embodiment. In the sixth embodiment, the batch of n commands in the queue buffer memory is associated with an overall completion time limit, i.e. the combination of n commands must be completed within a certain time limit, either a predetermined fixed time limit or a time limit communicated to the control circuit 90 in association with the commands.

The process of the sixth embodiment is comparable to the process of the fifth embodiment as described above, with the exception that, in step 511, the control circuit 90 also estimates, for each of the $2^n \cdot n!$ possible combinations of execution order and scanning mode setting, the estimated time required for completing the batch of n commands; such a combination of execution order and scanning mode setting is only taken into account if the estimated overall completion time is less than said overall completion time limit. Thus, even if a certain combination of execution order and scanning mode setting were to be more energy-efficient, this combination would not be selected if it involves more execution time than the time limit.

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EXAMPLE 7

A seventh embodiment of a read/write process in accordance with the present invention is also a combination of the fifth and the second embodiment. In the seventh embodiment, the batch of n commands in the queue buffer memory contains at least one command which is associated with an individual completion time limit, i.e. this command must be completed within a certain time limit, either a predetermined fixed time limit or a time limit communicated to the control circuit 90 in association with this command. The batch of n commands may comprise multiple commands associated with individual time limits; the respective individual time limits may be mutually different.

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The process of the seventh embodiment is comparable to the process of the fifth embodiment as described above, with the exception that, in step 511, the control circuit 90 also estimates, for each of the $2^n \cdot n!$ possible combinations of execution order and scanning mode setting, the estimated time required for completing each individual command (or at least the commands associated with an individual time limit); such a combination of execution order and scanning mode setting is only taken into account if, for each individual command, the estimated individual completion time is less than the corresponding individual completion time limit. Thus, even if a certain combination of execution order and scanning mode setting were to be more energy-efficient, this combination would not be selected if it involves even a single command surpassing its individual completion time limit.

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It should be clear to a person skilled in the art that the present invention is not limited to the exemplary embodiments discussed above, but that several variations and modifications are possible within the protective scope of the invention as defined in the appending claims. For instance, even when maintaining the CLV mode, it is possible to select different linear velocities for executing different commands. The disc drive may have

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different pre-defined linear velocities available. When estimating a minimum amount of energy consumption, the disc drive may vary the linear velocity and perform calculations for each of the pre-defined linear velocities. These variations may be on the basis of one velocity for all tasks, or on the basis of independent velocities for different tasks.

5 Likewise, even when maintaining the CAV mode, it is possible to select different angular velocities for executing different commands. The disc drive may have different pre-defined angular velocities available. When estimating a minimum amount of energy consumption, the disc drive may vary the angular velocity and perform calculations for each of the pre-defined angular velocities. These variations may be on the basis of one
10 velocity for all tasks, or on the basis of independent velocities for different tasks.

 Further, a combination of the sixth and the seventh embodiment is possible, in that an overall completion time limit applies to the batch of scanning commands while also an individual execution time limit applies to at least one individual scanning command.

 Further, overall and/or individual time constraints may also apply to the fourth
15 and the fifth embodiment.

 In the above, the present invention has been explained with reference to block diagrams, which illustrate functional blocks of the device according to the present invention. It is to be understood that one or more of these functional blocks may be implemented in hardware, where the function of such a functional block is performed by individual hardware
20 components, but it is also possible that one or more of these functional blocks are implemented in software, so that the function of such a functional block is performed by one or more program lines of a computer program or a programmable device such as a microprocessor, microcontroller, digital signal processor, etc.